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Guidance for comparison of toxic gas data between different physical fire models and scales

Lignes directrices pour la comparaison de données de gaz toxiques entre divers modèles et échelles de feu physiques

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 29903 was prepared by Technical Committee ISO/TC 92, *Fire Safety*, Subcommittee SC 3, *Fire threat to people and the environment*.

Introduction

The production of toxic gases in fires can be a significant factor in determining whether people escape from a fire or not. Estimation of the time available for escape and the time required for escape each require values of the concentrations of toxic gases along possible escape paths. Typically, the yields of the gases from burning finished products are estimated or measured prior to conducting such calculations. In some rare cases toxic species production can be calculated during modelling of the fire development. Typically spread of the gases and their dilution with air is then simulated using equations or computational models.

The yields of these gases can be measured in a real-scale laboratory test of the entire finished product (e.g. a chair) or in a bench-scale test (using a physical fire model) of a specimen cut from the product or a component of the product. Since there are thousands of different combustibles, routine real-scale testing is both costly and impractical. Thus, there is a need to develop reliable methods to use physical fire models, conducted in less than real-scale, for the estimation of real-scale emissions.

The yields of the gases from the real-scale test are often considered to be the accurate values for the particular test conditions. In tests involving a portion of the finished product in a physical fire model, the specimen characteristics and the combustion conditions differ from those in the real-scale test. In most cases the physical fire model reproduces one part of the entire real-scale scenario, e.g. initial well ventilated conditions or later vitiated conditions. The yields of combustion products in a fire test depend on apparatus conditions such as: the fuel/air equivalence ratio, whether the decomposition is flaming or non-flaming, the persistence of flaming of the sample, the temperature of the specimen and the effluents produced, the stability of the decomposition conditions, and the interaction of the apparatus with the decomposition process, with the effluents and with the flames.

It is, therefore, important to have a standardised methodology for comparing the toxic gas yields generated in tests of different scales to determine the appropriateness of using the data from individual physical fire models in fire hazard and risk assessment. It is also valuable to be able to compare the yield data from different physical fire models to determine whether or when they generate comparable results.

This International Standard concerns the comparison of toxic gas data between small-scale (physical fire models) and large-scale tests and between different small-scale tests, i.e. it covers

a)   the comparison of toxic gas data from fire tests of different physical scales and characteristics in terms of a methodology to identify whether the data are comparable and (provided it is comparable) how to make relevant comparisons, and

b)   the prediction of large-scale results based on small-scale test data or vice versa.

Guidance for comparison of toxic gas data between different physical fire models and scales

1 Scope

This International Standard provides principles for characterizing the measured production of toxic gases from a laboratory fire test and provides bases for comparing the results between different types and scales of such tests. It also includes consideration of the uncertainties in the gas determinations. The combined uncertainty is a key factor in the ability to establish similarity or difference of test results.

The sufficiency of the agreement between a bench-scale test and a real-scale test depends on the precision needed in the fire hazard or risk assessment, which is not covered by ISO 29903:2012.

This International Standard defines the relevance and significance of toxic gas data from measurements in different fire tests. With such a definition it is possible to provide generic guidance on how such data can be compared between different sizes and types of fire tests.

The combustion conditions represented by the fire test, other specific characteristics of the test and the test specimen, the sampling strategy of the fire effluents, and the analysis technique for the toxic gas species are the most important factors when defining the significance of the toxic gas data.

This International Standard is intended to serve as a tool for the

a) definition of the relevance and significance of toxic gas data from fire tests,

b) comparison of toxic gas data from fire tests of different scales and characteristics, and

c) prediction of toxic gas data from a large-scale test based on small-scale data or vice versa.

This International Standard gives general guidance regarding comparison of toxic gas data between physical fire models of different scales, but is principally developed for the gases listed in ISO 13571, i.e. carbon dioxide (CO_2), carbon monoxide (CO), hydrogen halides (HCl, HBr, HF), sulfur dioxide (SO_2), hydrogen cyanide (HCN), nitrogen oxides (NO, NO_2), formaldehyde (CH_2O) and acrolein (C_3H_4O).

This International Standard does not cover characterization and comparisons of the toxicity of the effluents from fire tests.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

ISO 13571, *Life-threatening components of fire — Guidelines for the estimation of time available for escape using fire data*

ISO 13943, *Fire safety — Vocabulary*

ISO 16730, *Fire safety engineering — Assessment, verification and validation of calculation methods*

ISO 19706, *Guidelines for assessing the fire threat to people*

3   Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943, ISO 5725-1 and the following apply.

3.1
small-scale fire test
fire test performed on a test specimen of small dimensions

NOTE 1   The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2   Such a test is synonymously referred to as a "bench-scale test."

NOTE 3   In these tests, the typical maximum length of a linear test specimen is less than 1 m. The typical maximum dimensions of a rectangular specimen are approximately 0.1 m.

3.2
medium-scale fire test
fire test performed on a test specimen of small-medium size dimensions

NOTE   A fire test performed on a test specimen of which the maximum dimension is between 0.5 m and 1.0 m is here called a medium-scale fire test.

3.3
intermediate-scale fire test
fire test performed on a test specimen of medium dimensions

NOTE 1   The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2   A fire test performed on a test specimen for which the maximum dimension is between 1 m and 3 m is usually called an intermediate-scale fire test.

3.4
large-scale fire test
fire test, that cannot be carried out in a typical laboratory chamber, performed on a test specimen of large dimensions

NOTE 1   The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2   A fire test performed on a test specimen of which the maximum dimension is greater than 3 m is usually called a large-scale fire test.

3.5
real-scale fire test
fire test that simulates a given application, taking into account the real scale, the real way the item is installed and used, and the environment

NOTE 1   The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2   Such a fire test normally assumes that the products are used in accordance with the conditions laid down by the specifier and/or in accordance with normal practice.

3.6
matrix effect
combined effect of all components of the sample other than the analyte on the measurement of the quantity

NOTE 1   Matrix effect (in analytical chemistry) as defined in IUPAC Compendium of Chemical Terminology [1].

NOTE 2   The matrix effect in analysis of toxic gases in a fire effluent will be the combined effect from the components of the effluent on the analyte.

NOTE 3   If a specific component can be identified as causing an effect then this is referred to as interference.

4   Combustion conditions

4.1   General

The yields and nature of the fire effluent component from a fire test of any scale are determined by the involved fuels and the prevalent thermal and oxidative conditions in the current stage of the fire. These conditions also determine the burning rate of the products/materials and thus the rate of effluent generation. See ISO 16312-1.

During a fire test of a finished product, the combustion conditions are likely to change. These changes include the chemistry of the combustible item and the sufficiency of the ventilation.

Whether decomposition is flaming or non-flaming is a dominant factor in the production of toxic gases.

The combustion conditions under which toxic gas data are developed shall be as close to equivalent as possible between the physical fire models or test scales compared (see Clause 6).

NOTE 1   A large change in the rate of combustion may affect the degree of oxidation of the emitted effluent. Smaller changes in combustion rate may have no significant effect.

NOTE 2   Fire stages and the corresponding combustion conditions are described in ISO 19706.

4.2   Thermal environment

The thermal boundary conditions in a test include the external applied heat flux and the heat flux from any flaming combustion. Also of importance is the heat flux distribution among radiation, convection, and conduction.

The thermal environment sensed by the test specimen during combustion includes both gas temperature and the temperature of the sample material, as defined by the thermal boundary conditions.

4.3   Ventilation

The oxygen availability (ventilation) in the physical fire models compared determines the combustion conditions. Comparison among different methods requires characterization of the ventilation conditions in order to assess the degree of similarity.

For a given experiment, it is necessary to identify how the ventilation is characterized and whether the characterization is local or global.

For a physical fire model in which the fuel gasification rate and the entering oxygen flow and concentration are each controlled independently, the relative oxygen availability can be characterized by a fuel/oxygen equivalence ratio. For other models and real-scale fire tests, one or both of the terms in the equivalence ratio may not be well-known. In those cases, a broader characterization is used. This could be a global equivalence ratio or a term such as "underventilated burning" or "well ventilated burning."

NOTE 1   Methods for calculating equivalence ratios for physical fire models are given in ISO 19703.

NOTE 2   The local air speed rate can be a significant factor in some fire tests. This applies especially for a tube furnace, where the air speed can affect the results of the combustion.

4.4   Characteristics of test specimens

For finished products that consist of a single, homogeneous material, the test specimen used in a physical fire model shall be prepared to accommodate the constraints of the test apparatus.

For specimens from non-homogeneous products, the test specimen must also contain the same portions of the different materials present in the finished product in both tests compared.

For layered commercial products, an ideal physical fire model accommodates specimens that preserve the relationship of the layers. When this is not possible within the constraints of the model, the rationale for the configuration of the layers shall be documented.

NOTE   The yields of toxic gases can depend on the surface exposed, and the timing and extent of penetration of the layers.

5   Toxic gas data

5.1   Identification of toxic species

The minimum set of gases that shall be considered are listed in ISO 13571.

Additional gases shall be appraised as warranted by the chemical composition of the test specimen and the finished product from which it is sampled.

5.2   Different expressions for toxic gas data

5.2.1   General

Subclause 5.2 contains a summary of different expressions typically used for toxic gas data obtained from fire tests and whether the data are suitable for comparison with similar data from other tests or as a basis for the prediction of large scale results based on small scale data or vice versa.

The experimental data on toxic gases from a fire test can be expressed in several ways. From unrefined measurement data, which is often expressed as gas concentrations from a specific physical fire model, to data in higher degrees of refinement, e.g. yields. What is determined depends in part on the physical fire model used. See Annex A for information concerning the characteristics of different fire models.

The data can be in the form of scalar data or vector data. Some types of data are suitable for direct quantitative comparison, but others require a model for quantitative comparison. The most common quantities used in presentation of toxic gas data are given in Table 1 below.

Table 1 — Common types of data on toxic gases from fire tests and properties for comparison

Type of data	Typical units	SI-units	Scalar or vector data	Direct or indirect comparison	Qualitative or quantitative
Concentration of toxi-cants	ppm (v/v), i.e. µL/L	m^3/m^3	Scalar / Vector [a]	Indirect (Direct) [d]	Quantitative (Quali-tative [e])
The contribution to FED (or FEC) from individual toxicants	—	—	Scalar / Vector [a]	Indirect (Direct) [d]	Quantitative (Quali-tative [e])
Lethal toxic potency	g/m^3	kg/m^3	Scalar	Direct	Quantitative
Total amount of toxi-cants released	kg	kg	Scalar	Indirect (e.g. as yield)	Quantitative
Yields	g/g	kg/kg	Scalar (Vector) [b]	Direct	Quantitative
Production rates	g/s	kg/s	Vector (Scalar) [c]	Indirect (Direct) [d]	Quantitative (Quali-tative [e])
Normalized production rates	$g·s^{-1}·m^{-2}$	$kg·s^{-1}·m^{-2}$	Vector (Scalar) [c]	Direct	Quantitative

[a] Scalar if the model is steady-state or vector if the model studies changes in concentration over time.

[b] Typically calculated as scalar data for the whole experimental period but can be calculated as vector data at each point in time.

[c] Typically calculated as vector data at each point in time but can be calculated as scalar data for the whole experimental period.

[d] Indirect comparison using a model (as shown in Figure 1) allows quantitative comparison. In some cases direct comparison can be used for qualitative assessment.

[e] Direct comparisons without the use of a model can provide qualitative information.

NOTE   The "Type of data" given in Table 1 are explained in 5.2.2 – 5.2.7.

5.2.2 Yields

Yield is typically the recommended comparison parameter. Yield is the measured mass of a toxicant generated during combustion, per unit mass of test specimen consumed in the fire test (mass loss) or alternatively, per unit mass of specimen exposed (mass-charge). The calculation of yields is defined in ISO 19703.

Yield is a quantitative comparison parameter and is independent of dilution or other apparatus specific parameters which do not impact on the combustion conditions.

NOTE 1   It can be difficult to calculate toxic gas yields in some large-scale physical fire models (e.g. ISO 9705), as the mass loss is normally not measured in these tests.

NOTE 2   Yield can be expressed relative to mass loss rate and thereby provide kinetic information or be a unique value representing an average of the complete test.

5.2.2.1   Mass of a toxic gas generated

A measurement or approximation of the mass of the toxic gas generated is essential to the calculation of toxic gas yields. The typical gas measurement during a fire test is the volumetric concentration of the gas in a volumetric sample of the total effluent. If the effluent from the fire test is not fully mixed, multiple concentration measurements across the effluent flow are necessary.

The concentration measurement shall be converted to a mass of the toxic gas generated during the sampling time interval using the ideal gas law. Corrections for condensation, solution, and deposition of the gas shall be included, as appropriate, in the calculation.

5.2.2.2   Mass of the test specimen consumed

A measurement or approximation of the consumed mass of the specimen is essential to the calculation of toxic gas yields.

The mass consumed shall be calculated in at least one of three ways.

— Mass loss based on continuous measurement of the remaining mass of the test specimen.

— Mass loss based on a final measurement of the remaining specimen mass.

— Estimation of the mass loss, when no gravimetric measurement is possible, using the chemical formulation of the test specimen and a carbon balance of the combustion products.

NOTE   The third method can be in significant error if the chemical composition of the specimen residue is not the same as the initial chemical composition. This error can be reduced by determining the chemical composition of the residue.

5.2.3   Concentrations of toxicants

The concentrations measured in a specific physical fire model are a function of the degree of dilution in the sampling point. Concentrations are unique for the specific physical fire model and should not be used for a direct quantitative comparison. The agreement of relative concentrations between different physical fire models, can however be used for comparison.

The CO/CO_2 concentration ratio, for example, can be used as a comparison principle (see 6.2.2).

NOTE   Concentrations are normally expressed as volume fractions.

5.2.4   The contribution to FED (or FEC) from individual toxicants

The ranking of the different toxicants measured based on the relative contribution to the total toxicity using the FED (or FEC) concept is a semiquantitative comparison principle. The measured concentrations of toxicants are weighted relative to lethality, or incapacitation limits, e.g. LC_{50}. See ISO 13344.

5.2.5   Lethal toxic potency

Total lethal toxic potency of the fire effluents measured from the physical fire model is a quantitative comparison parameter. The predicted lethal toxic potency (LC50) has the unit g/m^3 and requires data on mass loss or mass charge. The concept of lethal toxic potency referred to here is defined in ISO 13344.

5.2.6   Total amount of toxicant released

The total amount of a toxicant produced from a test is a unique parameter for a specific test only and is not a suitable comparison parameter unless weighted against surface area of sample, sample mass or mass loss.

5.2.7   Production rates

The production rate is temporally resolved data concerning the measured mass of a toxicant generated during combustion, e.g. expressed in g/s.

The production rate can be normalized relative to, e.g. the exposed surface area, and is in that case expressed in $g \cdot s^{-1} \cdot m^{-2}$. Normalized production rates are directly comparable quantitative parameters.

5.3   Significance of analysis data

5.3.1   General

It is important to ascertain that the analytical techniques used for measurement of the toxic gas components compared between fire models, give comparable data. Factors to take into consideration are

— resolution of data,

— response time,

— selectivity of analytical technique, and

— effect of matrix.

Regarding selectivity, the same individual toxicants must be included in a comparison. This is important if data are expressed as "total values" as is sometimes the case when referring to oxides of nitrogen (NOx) or to polycyclic aromatic hydrocarbons (PAH).

The measurement matrix can induce errors and interfere with the analytical method. An assessment of possible matrix effects must always be made as fire effluents is a difficult and variable matrix.

NOTE   An example of influence of resolution is the comparison of the analytical results from methods giving peak-value data and methods giving averaged data.

5.3.2   Limit of detection (LoD)

If a specific toxicant is not identified in any of the scales compared, and if the LoD on both scales is toxicologically insignificant (see ISO 13571), then this information concerning the specific toxicant is sufficient for comparison based on LoD alone. That is, a numerical comparison is not important.

If the LoD-value for a certain toxic gas results in a fractional effective dose/concentration that is insignificant relative to the total fractional effective dose/concentration for the sum of toxic gases present, the maximum contribution (i.e. LoD) from that gas could be regarded as insignificant.

NOTE 1   Information on methods for calculating limit of detection and limit of quantification are given in ISO 12828-1 [2].

NOTE 2   Methods for calculating fractional effective doses for asphyxiants and fractional effective concentrations for irritants are given in ISO 13571.

5.3.3   Measurement uncertainty

The trueness, repeatability, and reproducibility of analytical methods must be known and taken into consideration in a determination of the measurement uncertainty.

NOTE 1   Methods for determination of the measurement uncertainty are given in ISO/IEC Guide 98-3 [3].

NOTE 2   For definitions of trueness, repeatability and reproducibility see ISO 5725-1.

6   Comparison/prediction of toxic gas data from different physical fire models

6.1   General

The toxic gas data determined according to Clause 5 must be compared for the same combustion conditions as defined in Clause 4. Different principles can be applied for the comparisons of yields from different physical fire models, i.e. similar fire stages, CO/CO_2 ratios or equivalence ratios, see 6.2. Which methodology should be used for comparison of toxic gas data is dependent not only on which comparison principle is used but also on whether the comparison is direct or indirect as described in 6.3.1. The corresponding methodology for prediction of toxic gas data from one physical fire model based on another is given in 6.4.

Yield is the recommended comparison parameter although other parameters could be compared, see 5.2.

6.2 Comparison principles

6.2.1 Fire stages

The fire stage simulated by the physical fire model shall be determined in accordance with ISO 19706. If the combustion of the sample encompasses more than one fire stage during a test, the time interval for each fire stage shall be identified.

Comparison of toxic gas yields shall be for the same fire stage or for a succession of identical fire stages. For tests in which there is a succession of fire stages a basis for the contribution of each stage to the toxic gas yields must be determined, e.g. the equivalence ratio.

NOTE 1   For smouldering combustion, (fire stage 1.a in ISO 19706), the equivalence ratio is difficult to define.

NOTE 2   For oxidative pyrolysis (fire stage 1.b in ISO 19706), there are insufficient experimental data on which to base an estimate of dependence of toxic product yields on equivalence ratio.

NOTE 3   For anaerobic pyrolysis (fire stage 1.c in ISO 19706), there is no oxygen present, and thus the equivalence ratio concept is immaterial.

NOTE 4   For well-ventilated flaming fire conditions (fire stage 2 in ISO 19706), where the fuel/air equivalence ratio is less than 0.5, the yields of some important toxic gases have been shown to be relatively insensitive to the equivalence ratio.

NOTE 5   For underventilated flaming fire conditions (fire stage 3 in ISO 19706), where the fuel/air equivalence ratio is approximately 1 or higher, the yields of some important toxic gases have been shown to be sensitive to the value of the equivalence ratio.

6.2.2 CO/CO_2-ratio

The CO/CO_2-ratio reflects the availability of oxygen for combustion and thus describes the combustion conditions in many cases. The CO/CO_2-ratio measured from physical fire models can, in some cases, be used as the basis for comparison.

This principle is not appropriate for sample materials containing halogens (e.g. PVC materials) as halogens interfere with the gas phase combustion process and promote CO-production irrespective of the prevailing combustion conditions.

The combustion temperature and the upper layer temperature in a large-scale test could influence the production of toxic gases and must be taken into account.

NOTE 1   ISO 19706 uses the CO/CO_2-ratio in characterization of the different stages of a fire. CO_2/CO-ratio can alternatively be used to avoid working with small decimal numbers with the same result.

NOTE 2   In large-scale fire tests the CO/CO_2-ratio may vary depending on the sampling point, which is an effect of post fire reactions with oxidation of CO to CO_2 downstream of the sampling point.

6.2.3 Equivalence ratio

The fuel/air equivalence ratio describes the amount of oxygen available for the combustion reactions compared to the stoichiometric need for complete combustion to CO_2 and H_2O and is suitable as a basis of comparison. The equivalence ratio can be measured in a fire test using special measurement devices [4] or calculated from the mass loss of the sample and the oxygen flow to the combustion site.

Boundaries for the equivalence ratio have to be defined for the physical fire model; a local equivalence ratio for the combustion or a global equivalence ratio for the total volume of e.g. a test compartment.

The combustion temperature and the upper layer temperature in a large-scale test could influence the production of toxic gases and must be taken into account.

NOTE   The calculation of equivalence ratios is described in ISO 19703.

6.3   Comparison methodology

6.3.1   General

The primary basis for comparison of data from different tests is the yield of each toxic gas. The yield data are determined from a test specimen of a material burning under conditions simulating a specific fire stage using a specific bench-scale physical fire model. These data are compared with toxic gas yield data from the same stage of burning using another bench-scale physical fire model, or using a large-scale test of a finished product.

For data concerning toxic gases suitable for a direct comparison (see 5.2.1) the data can be compared directly between fire tests of different scales. For data on toxic gases not suitable for a direct comparison (see 5.2.1), a model is required in order to facilitate an indirect comparison. Such a model may include dilution factors, a factor for normalization of exposed fuel surfaces or other methods for recalculating the original data in a format for comparison.

The two different cases of comparison, direct comparison and indirect comparison, are illustrated in Figure 1.

The comparison methodology is defined in 6.3.2-6.3.4 and outlined in Figure 2.

NOTE 1   See ISO 16312-1 for accuracy of physical fire models.

NOTE 2   CEN/TS 45545-2 [5] is an example of a technical specification including test requirements for toxicity where normalization models (a model for indirect comparison) for toxic gases are used.
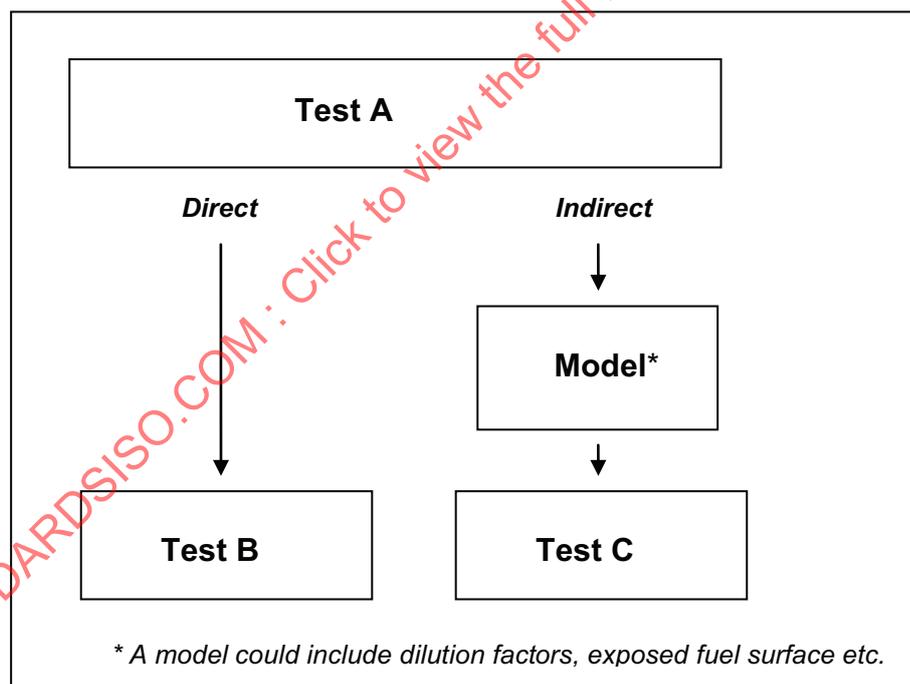

Figure 1 — Schematic figure of direct and indirect comparison of toxic gas data

6.3.2   Assessment of available data

The first assessment of available data requires determination of the combustion conditions of the two tests compared, for the periods where the gas production data are compared. If the combustion conditions are not comparable, the data on toxic gases cannot be compared between the two tests.

Once it has been established that the combustion conditions are comparable, an assessment of the sampling and analysis techniques used is made. Correction of the data based on sampling and analysis methods should be made as outlined in Annex B.

The type of data available from the two tests selected for comparison (e.g. yields) should be assessed to ascertain that the data are comparable. Finally, it is necessary to make an assessment of the measurement uncertainty for the data compared from the two tests. For a meaningful comparison the measurement uncertainties should not differ in magnitude.

NOTE   For well-ventilated tests the exact agreement in equivalence ratio is of less importance compared to tests with varying degrees of vitiation where the equivalence ratio is critical for the production of most toxic gases (see 6.2.3). Where possible, comparison of a specific toxic species between different physical fire models or between a physical fire model and a real-scale fire test should be based on the yields of the specific toxic species generated under comparable combustion conditions, as this type of comparison generally provides the best agreement or prediction capability.

6.3.3   Comparison of data

Select the comparison principle for the toxic gas data (see 6.2) based on the assessment made in 6.3.2.

For an indirect comparison apply an appropriate scaling model to the data (see Figure 1).

Compare the data for each selected toxic gas and make an assessment of the numerical agreement based on the overlap between the numerical ranges defined by their respective measurement uncertainties.

For comparison of vector data, the methodology for comparison of vector data as specified in ISO 16730 shall be used.

NOTE   ISO 16730 addresses the assessment, verification and validation of calculation methods for fire safety engineering in general. Annex B of ISO 16730 describes a method to quantify the similarities and differences of two curves such as the time history of the upper layer temperature for a model prediction and an experiment. This is done by treating the curves as infinite dimensional vectors and then using vector analysis to describe the differences. This analysis provides a quantitative method of verifying fire models and quantifying the uncertainty in experimental data. While there is a variety of numbers that could be generated to describe the differences between two curves or a set of curves, two values are focused on as giving appropriate information for determining the differences. The first, relative difference, gives a value for how different the two curves are. It is a positive real valued function that gives a 0 for identical curves and the larger the value the larger the difference. The second, the cosine, gives a measure of how the shapes of the two curves compare. It returns values from 1 to −1 with 1 meaning the curves have the same shape and −1 meaning the curves are mirror images and 0 if the curves have nothing in common. Annex B of ISO 16730 describes the method and appropriate formulae and shows examples of how to do the comparison.

6.3.4   Assessment of agreement

Agreement between two physical fire models or a physical fire model and a real-scale test is affirmed if the yields of all toxic gases are in agreement.

In cases when the comparison of an individual toxic gas component does not agree (outlier) the models/tests compared could still be in general agreement. An explanation of the reason for the outlying toxic gas component should be found.

If an outlier is due to differences in combustion conditions between the models/tests compared, the comparison between these sets of data shall be regarded as not valid.

NOTE 1   Requirements for agreement between a bench-scale fire test and a real-scale fire test are given in ISO 16312-1.

NOTE 2   An explanation for an outlier can often be found through re-assessment of the sampling and analysis of that toxic gas component.
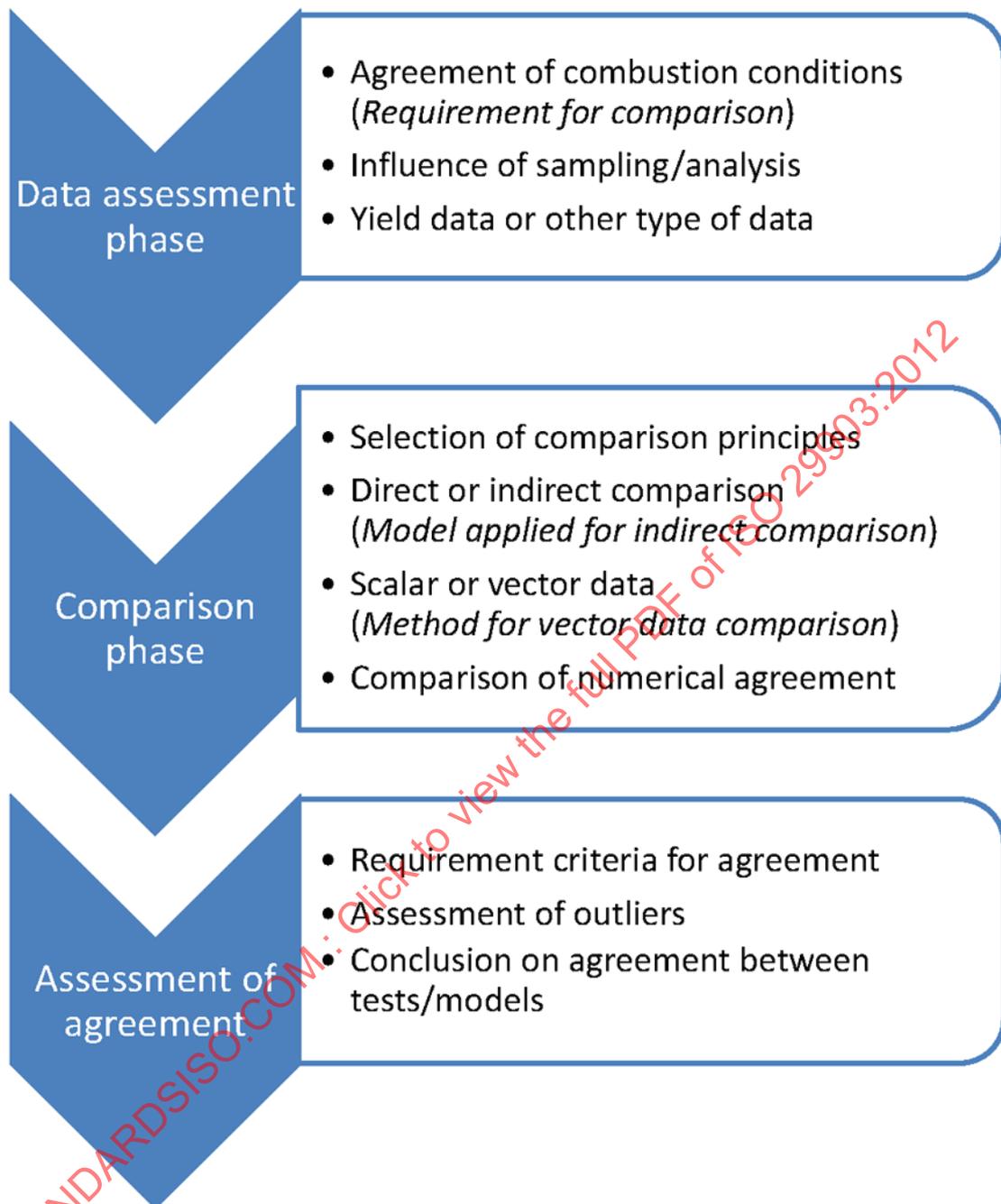
Figure 2 — Flow chart of comparison methodology

6.4   Prediction of data from one fire model to another

Toxic gas data can be predicted in one scale based on results from another if it has been shown that data from these models are comparable using the principles given in 6.3.

If, for example, the fire models of smaller and larger scale of the same fire stage have shown correlation, it is possible to use the results from one such model to predict the results from the other model. The method for prediction will depend on the type of information to be scaled.

7 Documentation

A report or any other documentation shall include the following information for each fire test included in a comparison:

a) The fire tests for which the toxic gas data are being compared.

b) The fire stage(s) examined and the prevailing combustion conditions.

c) The type of data compared (e.g. yields) and any assumptions in calculations of final data used in the comparison.

d) Any influence of sampling and analysis techniques used.

e) The uncertainties in the measurements and the cumulative uncertainty in the final data used in the comparison.

f) The comparison principle used (i.e. fire stage, CO/CO_2 ratio or Equivalence ratio).

g) If direct or indirect comparison is made.

h) The comparison model used in the case on an indirect comparison.

i) The result of the comparison and the basis for determining the degree of agreement.

Annex A
(informative)

Characteristics of physical fire models

A.1   General

Bench-scale tests used for toxicity testing are ideally designed to reproduce a single fire stage/combustion condition. In large/real-scale tests, different and variable combustion conditions can be present simultaneously at different locations in the test system. Even if this is not the case, large/real-scale tests will often exhibit different fire stages/combustion conditions at different times during the test.

In a comparison of data concerning toxic gases between different fire tests it is necessary to consider the purpose and aim of the tests compared. Table A.1 summarizes the scales and parameters studied by some common fire test methods.

NOTE   For example, a large open pool fire with nominally well-ventilated conditions contains different zones of local combustion conditions, from the centre of the pool with a lack of oxygen and a high heat flux to the periphery of the pool where there is good availability of oxygen and effective combustion. During a large-scale enclosure fire test, the fire can pass from one fire stage to another, from well-ventilated pre-flashover to under-ventilated post-flashover conditions. The variability of the combustion conditions in large-scale tests must be considered in a comparison.

Table A.1 — Scale and parameters of some common fire test methods

Size / Scale	Parameter studied	Example of fire tests
Material / Bench-scale	Potency of release of toxic combustion products	— ISO/TS 19700 [6] — NF X 70-100 [7]
Finished material / Bench-scale	(+) Multi-layer thermal / physical / chemical effects	— ISO 5660 [8] — ISO 12136 [9] — ISO 5659-2 [10]
Semi-finished product / Medium-scale	(+) Fire growth	— ISO 21367 [11]
Finished product / Intermediate-scale	(+) Joints and assemblies (+) Mounting and fixing (partial)	— EN 13823 [12]
Finished building / Large-scale	(+) Mounting and fixing in real conditions	— ISO 9705 [13] — ISO 13784-1 [14]
Real-scale	(+) Real-scale end-use conditions	— ISO 24473 [15] — Real-scale ad hoc tests

NOTE 1   The different parameters additionally included with an increase in scale are marked with a (+) in Table 1.

NOTE 2   The test methods given as examples in Table A.1 could allow toxic gas measurement even if this is not included in the standard test protocol at present.

A.2 Bench-scale tests

A.2.1 General

A general characterization of a bench-scale test appropriate for obtaining data on fire effluent toxicity can be found in ISO 16312-1. Individual bench-scale tests are characterized and evaluated for their utility for generating fire effluent toxicity data in ISO 16312-2.

A.2.2 Tests with constant combustion conditions

Physical fire models capable of attaining constant combustion conditions during the complete test or for prolonged steady-state periods are most fitting for producing toxic gas data suitable for comparison and interpolation. Only a few test methods belong to this category.

NOTE   The ISO tube furnace method, ISO/TS 19700 [6], the equivalent IEC tube furnace method, IEC 60695-7-50 [16] and the German tube furnace method, DIN 53436 [17], are examples of flow-through tests which are designed for attaining constant combustion conditions throughout the test period. In these tests the oxygen flow and the fuel flow through the hot zone of the apparatus can be regulated to attain the desired combustion condition.

A.2.3 Tests with non-constant combustion condition

Most bench-scale tests fall into this category. This includes all tests where the test specimen is placed stationary in a closed or semi-closed test apparatus and is exposed to a constant source of heat. The specimen itself will in such cases influence the conditions by its reaction-to-fire behaviour and its finite mass.

This includes stationary tube furnace tests as e.g. the French test, NF X 70-100 [7], where the combustion conditions will vary by the burning-phases of the test specimen through the test.

This includes closed cabinet tests, e.g. applications with the ISO 5659-2 smoke box [10] such as that by the International Maritime Organization [18], where the combustion effluents from the tests specimen will vitiate the atmosphere in the cabinet as the test proceeds.

A category of bench-scale tests that can produce partially constant combustion condition includes the Cone Calorimeter ISO 5660-1 [8], and the Fire Propagation Apparatus ASTM E 2058 [19]. For both of these tests a stationary sample is heated and ignited under exposure from a radiant source.

NOTE   Of these methods the Cone Calorimeter is the most widespread apparatus, although the Fire Propagation Apparatus is the apparatus most suitable for toxicity testing as the oxygen flow for the combustion can be regulated.

A.3 Large-scale tests

A.3.1 General

Large-scale tests normally involve testing of a finished product, which can contain different materials and layers. Further, the combustion conditions in large-scale tests can include several fire stages as a result of the burning-phases of the test specimen.

A.3.2 Enclosure tests

Enclosure tests can include several fire stages depending on the reaction to fire behaviour of the tested product. The combustion conditions can proceed from initial non-flaming oxidative pyrolysis, through

well-ventilated flaming, to reach under-ventilated flaming conditions in a post-flashover fire. ISO 9705 [13] [20] and ISO/TS 17431 [21] are examples of enclosure tests.

NOTE 1   ISO 9705 evaluates the reaction-to-fire properties of surface lining products. This is the large scale reference test for the European fire classification of building products. ISO 9705 specifies a test method that simulates a fire that under well-ventilated conditions starts in a corner of a room with a single open doorway. Depending on the material tested the fire can spread along the walls and ceiling and the test may reach flashover with flames reaching out of the doorway. The combustion conditions can, therefore, change from well-ventilated with a small flow of combustion gases leaving the room through the opening, to under-ventilated producing massive volumes of concentrated fire effluents.

NOTE 2   The mass loss can normally not be monitored directly in enclosure tests where surface lining products are mounted on walls and ceiling. This excludes calculations of yields for selected periods of the test.

NOTE 3   ISO/TS 17431 is an intermediate scale enclosure test that essentially is a reduced size ISO 9705 room. The test is primarily intended to evaluate the contribution to toxic hazard in, and potential for fire spread to, evacuation routes connected to the room of origin in which surface products are installed. The reduced size of the test makes it especially suitable for products with which a full-scale room test has to be terminated before the full involvement of the room in the fire due to the occurrence of flashover or for other safety reasons.

NOTE 4   The smaller size of the intermediate scale enclosure makes it suitable to be placed on a scale to monitor the mass loss during the test. This makes it possible to calculate yields for selected periods of the test.

A.3.3   Open tests

This includes large-scale tests where the test specimen is placed freely with no restriction of air for the combustion. This implies that the global combustion condition is of a single fire stage, a well-ventilated fire. An example of an open large-scale test is the open calorimeter, ISO 24473 [15].

NOTE 1   ISO 24473 specifies a series of test methods that simulate a real-scale fire with a test specimen or group of test specimens under well-ventilated conditions. A range of different fire sizes can be studied depending on the scale of the equipment available. The method is intended to evaluate the contribution to fire growth provided by a test specimen or group of test specimens using a specified ignition source. The product is placed under a calorimeter hood and the fire effluents are collected by the hood, which makes the method suitable for the measurement of toxic gases.

NOTE 2   The test specimen can be placed on a scale to monitor the mass loss during the test. This makes it possible to calculate species yields for selected periods of the test.

Annex B
(informative)

Influence of sampling and analysis on toxic gas data

B.1 General

Any differences in the techniques utilized for sampling and analysis of toxic gases have to be considered in a comparison of data between two different physical fire models. The location of the sampling point, the analysis resolution, and the sampling- and analysis technique, are all factors that influence the resulting data.

NOTE   Advice on proper sampling and analysis technique is given in ISO 19701 [22] and ISO 19702 [23]. Individual bench-scale tests are characterized and evaluated for their utility for generating fire effluent toxicity data in ISO 16312- 2.

B.2 Sampling position

The objective of proper sampling is to capture and transport a portion of the fire effluents to the analysis device without changing the fire effluents in the sampling process.

The sampling point should be located at a position such that the effluents at that point are representative of the desired combustion/ageing history of the effluents. Normally this entails the sampling of effluents that are cold enough to have ceased reacting, and warm enough to avoid condensation and ensuing losses. If the gases are not cold enough to have ceased reacting, the sampling system should quench further reaction, e.g. wall recombination of radical species.

For bench-scale fire tests, the sampling point is, in many cases, prescribed in the method standard. A general recommendation is that a sampling point shall be selected where the fire effluents have cooled sufficiently and are well-mixed.

For large-scale fire tests, there are often several possible sampling positions.

In enclosure tests the normal sampling position is in the duct of a smoke collection system, e.g. a hood/smoke gas collection systems as described in ISO 24473 [15]. This sampling position represents cooled and diluted fire effluents. This sampling position is preferred in many cases as matrix effects from the fire effluents are minimized by the dilution. A further advantage is that when fire effluents are quantitatively collected with the hood system, the production of toxic gases can be quantitatively measured. In the early stages of an enclosure fire, or when sampling from a small fire in an enclosure, however, the dilution of the fire effluents can result in concentrations below practical detection limits.

An alternative sampling position in an enclosure test, which can be preferred in certain cases, is in the top of the doorway, i.e. sampling from the undiluted out-flowing fire effluents. For such sampling it is important to ascertain that a representative sample is taken over the out-flowing area. It is further important to consider that hot fire gases sampled from the opening may not be sufficiently oxidized and will continue to react outside of the opening. For quantitative measurement of toxic gas production, the out-flow from the room must be quantified.

Another alternative sampling position in an enclosure test is at various positions within the enclosure. The results from such measurements are, however, only relevant for that specific test scenario and are not suitable for scaling.

In open tests where the fire effluents are collected by a hood/smoke gas collection system, the same considerations as those given above for enclosure tests, apply.

Alternative sampling positions in open tests are at various positions in the vicinity of the fire. The results from such measurements are, however, only relevant for that specific test scenario and are not suitable for scaling.

B.3   Ageing of smoke gases

The composition of the fire effluents is affected by the extent of dilution with fresh air which cools and quenches gas phase reactions, and the age of the effluents which determines the time available for post-fire processes including soot coagulation.

B.4   Deposition and losses

In enclosure tests, there is a risk for deposition of smoke gas effluents on the walls of the enclosure. There is also a high risk of losses of highly polar species such as e.g. HCl, by condensation in/on water or soot deposits on the walls.

These considerations are also valid for bench-scale closed cabinet tests.

NOTE   Wall losses could be expected to be more significant in bench-scale closed cabinet tests compared to large-scale enclosure tests as the wall area to chamber volume ratio is much higher for such tests.

B.5   Recovery

In enclosure tests, there is a risk of losses of products to the walls of the enclosures, in the sampling train in lines or filters, or during analysis. These losses can be quantified by expressing the recovery of different elements in the fire effluent and fuel residues as a function of the masses of specific elements in the fuels burned. For example, it is possible to determine the proportion of chlorine in a specimen recovered in hydrogen chloride in the fire effluent.

These considerations are also valid for bench-scale tests.

Annex C
(informative)

Application examples: Comparison of ISO 19700 bench-scale data with data from large-scale tests

## C.1 Yield data comparison using CO_2/CO-ratio as comparison principle

Stec et al. have compared yield data (mass loss based) of toxic gases between ISO/TS 19700 [6] bench-scale tests and large-scale tests with the ISO 9705 room [13]. They have used the CO_2/CO-ratio as the main comparison principle. They have further demonstrated the relationship between the measured CO_2/CO-ratio and the equivalence ratio. As yield data were available from both scales a direct comparison was possible. Information on measurement uncertainty was not available for the summary given here.

Stec et al. [24] have shown that the steady-state tube furnace (ISO/TS 19700) allows individual fire stages to be replicated and that the toxic gas data from the bench-scale model have a good general agreement with product yield data obtained from large-scale ISO room tests for the materials investigated. Their comparison includes CO_2, CO, HCN, NO_x, total hydrocarbons and smoke particulates. The materials investigated included polypropylene (PP), polyethylene (PE), polyamide 6.6 (PA 6.6), polystyrene (PS), medium density fibreboard (MDF) and fire resistant medium density fibreboard (MDF-FR).

For the tube-furnace experiments, data on the relationship between product yields and equivalence ratio were obtained for all materials. For some of the large-scale tests estimates of global equivalence ratio were made, while for others, the data necessary to calculate equivalence ratio were unavailable. As an alternative, the fire conditions were characterized by the CO_2/CO ratio, which was available for all experiments. For this reason the product yield data and comparisons were expressed as a function of CO_2/CO ratio.

For the large-scale tests where data or estimates of equivalence ratios were available, comparisons of equivalence ratios and CO_2/CO ratios are presented. Two of these comparisons are reproduced below. Figure C.1 shows the agreement in tests with PA 6.6 between room tests and tests with the steady-state tube furnace. The figure shows measured equivalence ratios in the opening of the test room plotted versus CO_2/CO ratios from measurements in the opening of the room, respective CO_2/CO ratios from measurements in the smoke gas duct where the effluents from the room were collected. The figure further includes equivalence ratios versus CO_2/CO ratios from the steady-state tube furnace. In these large-scale tests the fuel was placed in a pan in the room (pool fire) and mass loss was measured continuously.

The comparison in Figure C.1 shows differences between CO_2/CO ratios from measurements in the opening of the room (where the equivalence ratio was measured) and CO_2/CO ratios from measurements in the smoke gas duct. These differences indicate continued CO_2 formation after the door opening which results in higher CO_2/CO from the measurements in the duct. This is significant for the underventilated part of the tests (i.e. for phi-values above 1.0). There are some differences between the results from the tests with the steady-state tube furnace and the results from the large-scale tests but the general correlation is acceptable and shows that the tube furnace is able to represent large-scale conditions in terms of representative CO_2/CO ratios.
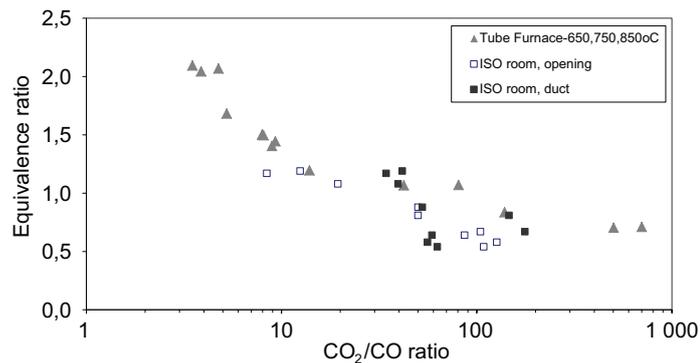
Figure C.1 — Relationship between equivalence ratio and CO_2/CO ratio for test with PA 6.6

Figure C.2 shows the agreement in tests with MDF between an estimated span for the equivalence ratio in the large-scale test and the data from the tube furnace. The MDF was mounted as a surface lining material in the large-scale tests, and there was thus no direct data on mass loss available. There is a quite significant difference between the results from the tube furnace and the large-scale tests. It is unclear if this difference is due to differences in the measured CO_2/CO ratios or if the difference instead is introduced from the estimations [24] of the equivalence ratio for the large-scale tests.
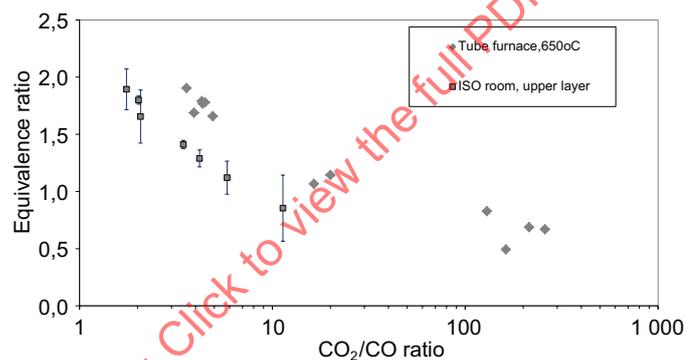


Figure C.2 — Relationship between equivalence ratio and CO_2/CO ratio for test with MDF

The closest direct agreement reported between the large and small-scale data was obtained for pool fires involving PP and PA 6.6 product yield. For materials burned as wall linings, with varying decomposition conditions at different room locations, and/or when a propane burner was also present, direct comparison with tube-furnace data was more problematic. Nevertheless MDF, MDF-FR and PS showed reasonable agreement for CO, CO_2, HCN and hydrocarbon yields between the scales.

Below are some examples of the comparisons made. The comparisons for CO and HCN in tests with PA 6.6 are shown in Figure C.3. The corresponding comparisons for tests with MDF board are shown in Figure C.4.

There is no information available on measurement uncertainties for the data from the two scales and the comparison presented here should be regarded as semiquantitative.
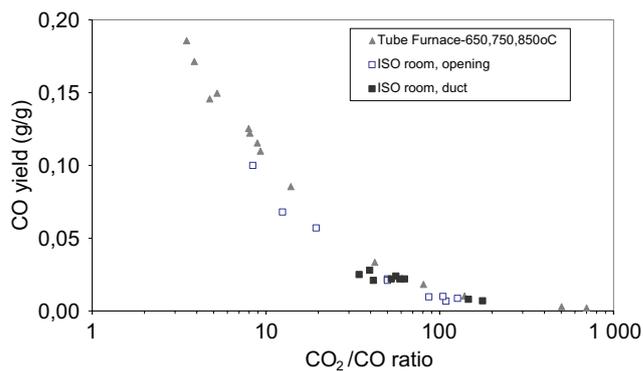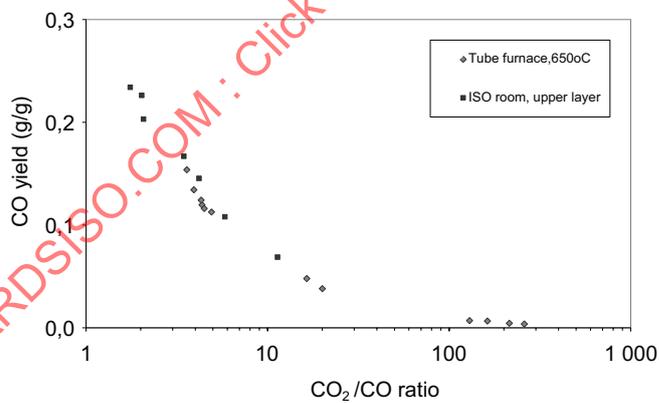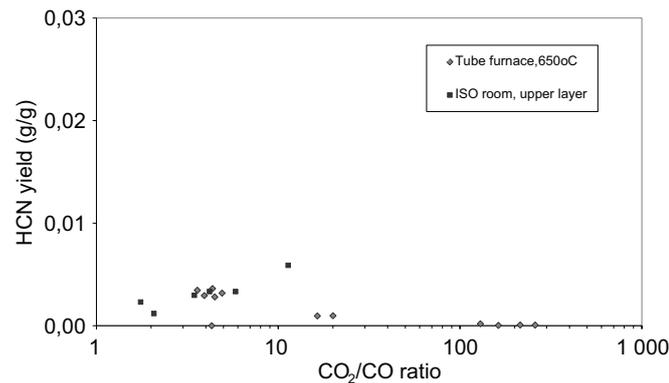
(a)
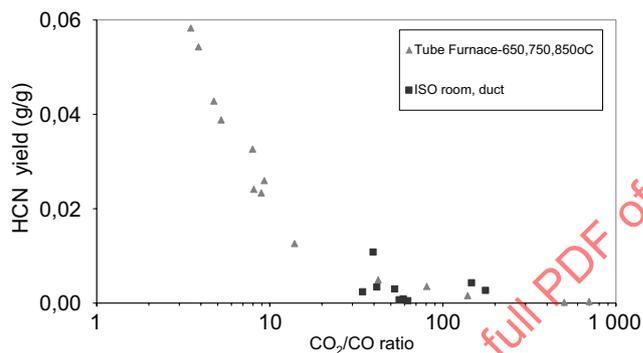
(b)

Figure C.3 — Comparison of (a) CO yields and (b) HCN yields, from tests with PA 6.6

(a)

(b)

Figure C.4 — Comparison of (a) CO yields and (b) HCN yields, from tests with MDF board

C.2 Yield data comparison using equivalence ratio as comparison principle

Blomqvist et al. have compared yield data (mass loss based) of toxic gases between bench-scale, large-scale tests and real-scale tests. They have used the equivalence ratio as the main comparison principle. Combustion conditions from well-ventilated to under-ventilated were assessed. As yield data were available from all scales, a direct comparison was possible. Information on measurement uncertainty was not available for the summary given here.

Blomqvist et al. have investigated the validity of the results from the ISO/TS 19700 [6] bench-scale method in replicating gas yields from large-scale fires [25]. A series of tests were conducted with PA 6.6 with the tube furnace method. The PA 6.6 tested with the tube furnace was from the same batch as the material previously tested in large-scale enclosure tests. The main large-scale test series was conducted using the ISO 9705 room [13], where both well ventilated and under-ventilated conditions were attained by restricting the opening of the room. In an additional series of tests, the size of the enclosure was increased and the fuel was placed in a storage configuration to simulate a real-scale storage situation. In both test series [26-27], the degree of ventilation was determined using a phi-meter [4]. PA 6.6 was previously tested in large-scale open pool fires experiments [28].

The main toxic gas measurements were made in the outflow of the opening in the enclosure tests using FTIR. CO_2 and CO were additionally measured on the diluted and well mixed gases in the smoke gas duct. NO_X was measured both in the opening and in the duct using dedicated NO_X-analysers. In the large-scale, open pool fires experiments, gas samples were extracted from the duct of the smoke gas collection system. FTIR was not used in these tests; instead wet-chemical methods together with dedicated gas analysers were used [28].

The yield data from the ISO/TS 19700 tube furnace tests with PA 6.6 was compared using the equivalence ratio. The general outcome of the comparisons made was favourable for ISO/TS 19700. But as no information was available on measurement uncertainties for the data from the different scales, the comparison presented below should be regarded as semiquantitative. For several gases, there was a strong correlation between the bench-scale yield data and data from the large-scale fire tests. HCN and NH_3 were measured in the openings of the two types of enclosures test. The tube furnace data generally correlated satisfactorily with the large scale data in these cases (see Figure C.5).